Wave Superposition

1. Two loudspeakers S_1 and S_2 are connected to a signal generator. The loudspeakers emit coherent sound waves.

State what is meant by the term **coherent**.

--- **[1]**

2. Monochromatic light is incident on a double slit.

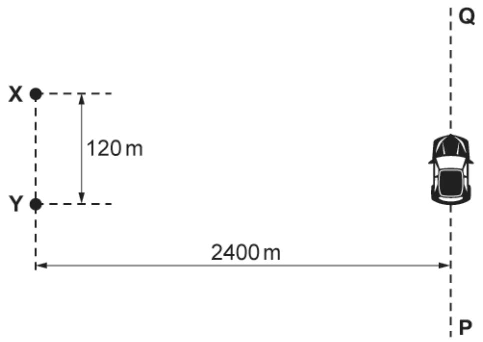
A pattern of dark and bright fringes is formed on a distant screen.

Which term, together with diffraction, can be used to explain these fringes?

A interference
B polarisation
C reflection
D refraction

Your answer ☐ **[1]**

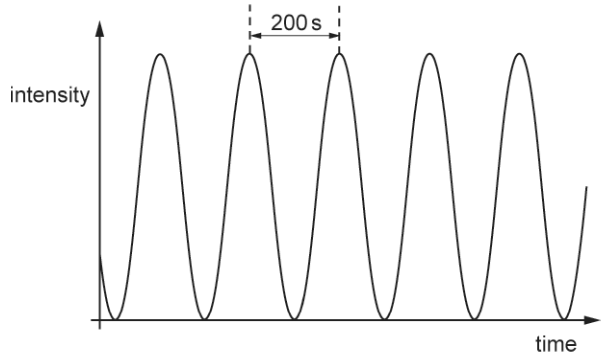
3. The diagram below shows two coherent sources of radio waves **X** and **Y**.



The diagram is **not** drawn to scale.

The radio waves are in phase at **X** and **Y**.
A car moves at a constant speed along the line **PQ**. The line **PQ** is parallel to line **XY**.
The separation between **X** and **Y** is 120 m.
The perpendicular distance between lines **PQ** and **XY** is 2400 m.

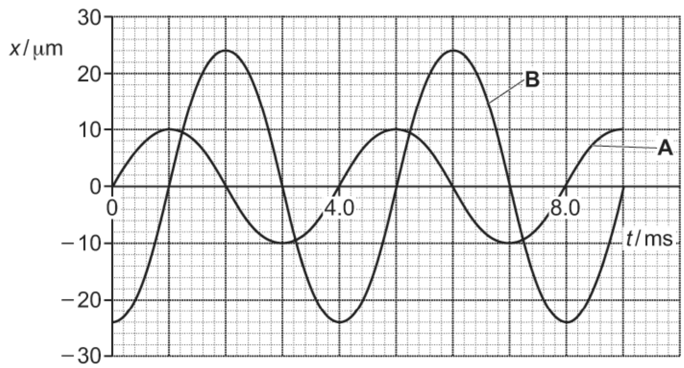
The intensity against time graph below shows the variation of the intensity of the radio waves at the position of the moving car.



State the **principle of superposition of waves**.

-- **[1]**

4 (a). Two progressive waves **A** and **B** meet at a point **P**.
The displacement *x* against time *t* graphs for **A** and **B** at the point **P** are shown below.



Explain how the graphs show that the waves are coherent.

-- **[1]**

(b). Determine the frequency *f* of the wave **A**.

f = ... Hz **[2]**

(c). The intensity of wave **A** is I_0.

Determine the intensity of wave **B** in terms of I_0.

intensity = ... I_0 **[2]**

(d). Determine the resultant displacement at the point **P** at time t = 2.5 ms.

resultant displacement = ... μm **[1]**

5. State what is meant by *coherent waves.*

----
[1]

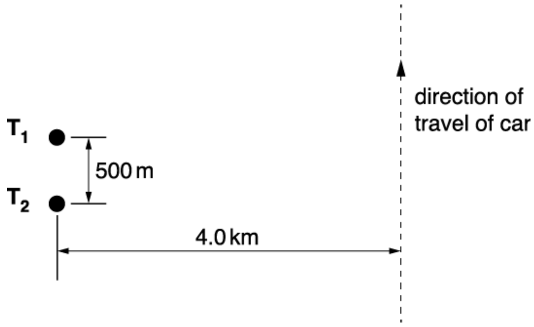
6. State the meaning of *coherence*.

----
[1]

7. State the **principle of superposition**.

----
[1]

8. Two radio wave transmitters **T_1** and **T_2** emit radio waves of wavelength 20 m. The separation between the transmitters is 500 m. The waves are in phase at the transmitters and have the same amplitude.
A car travels at a constant speed of 10 m s^{-1} in a straight line in a direction parallel to the line joining **T_1** and **T_2**. The perpendicular distance of the car from the line joining the transmitters is 4.0 km.



What is the time between two successive maximum signals detected at the car?

A 6.3×10^{-4} s
B 2.0 s
C 16 s
D 400 s

Your answer

[1]

9. A progressive wave of amplitude *a* has intensity *I*. This wave combines with another wave of amplitude 0.6*a* at a point in space. The phase difference between the waves is 180°.

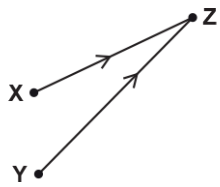
What is the resultant intensity of the combined waves in terms of *I*?

A 0.16 *I*
B 0.4 *I*
C 1.6 *I*
D 2.6 *I*

Your answer

[1]

10. Coherent radio waves from transmitters **X** and **Y** are emitted in phase. The waves interfere **constructively** at point **Z**.



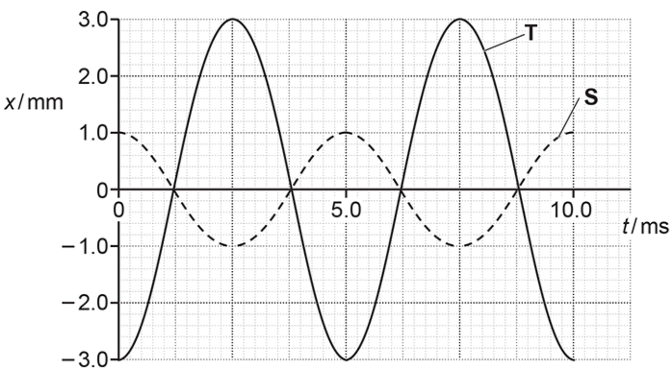
The distance **XZ** is 16.0 m and the distance **YZ** is 20.0 m.
The radio waves have wavelength λ.

Which value of λ is not possible?

A 1.0 m
B 2.0 m
C 3.0 m
D 4.0 m

Your answer [1]

11. The diagram below shows the graphs of displacement x against time t for two waves **S** and **T**.



The waves meet at a point in space.
The superposition of these two waves produces a resultant wave.

What is the frequency f and the amplitude A of the resultant wave?

A f = 100 Hz, A = 2.0 mm
B f = 100 Hz, A = 4.0 mm
C f = 200 Hz, A = 2.0 mm
D f = 200 Hz, A = 4.0 mm

Your answer [1]

12. A double-slit is used in an interference experiment to independently investigate the light from two sources **K** and **L**. The light from the sources have different wavelengths.
The table below shows some data.

Light source	**Wavelength of light**	**Separation between adjacent bright fringes**	**Distance between screen and double-slit**
K	λ	1.2 mm	D
L	0.80λ		0.50D

What is the separation between adjacent bright fringes for source L?

A 0.48 mm
B 1.2 mm
C 1.9 mm
D 3.0 mm

Your answer ☐ **[1]**

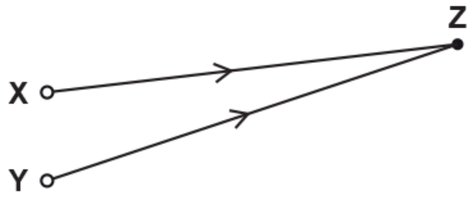
13. Monochromatic light from a laser is incident normally on a diffraction grating. A series of bright dots are formed on a distant screen.

Which **two** terms can be used to explain these bright dots?

A diffraction, interference
B reflection, interference
C refraction, diffraction
D refraction, reflection

Your answer ☐ **[1]**

14. The waves from the sources **X** and **Y** are coherent and have wavelength 10.0 cm.
The waves are in phase at **X** and **Y**.



Which row gives the correct conditions for constructive interference at point **Z**?

	Distance XZ / cm	Distance YZ / cm
A	60.0	75.0
B	75.0	95.0
C	90.0	65.0
D	100.0	135.0

Your answer [1]

15. The waves emitted from two sources are coherent.
Which quantity must be constant for these emitted waves?

A amplitude
B frequency
C intensity
D phase difference

Your answer [1]

16 (a). State the *principle of superposition* of waves.

--- [1]

(b). Fig. 16.1 shows an arrangement to demonstrate the interference of monochromatic light.

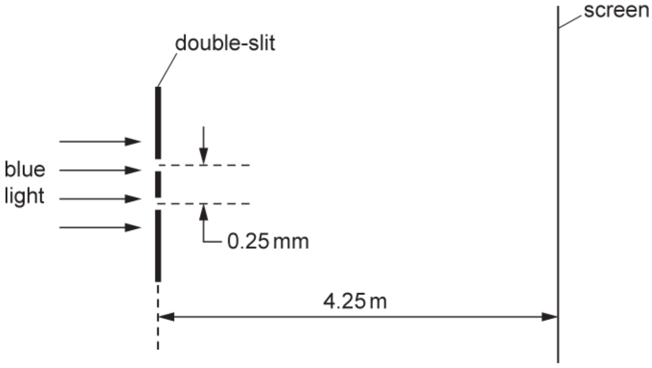


Fig. 16.1

Coherent blue light from a laser is incident at a double-slit. The separation between the slits is 0.25 mm. A series of dark and bright lines (fringes) appear on the screen. The screen is 4.25 m from the slits.
Fig. 16.2 shows the dark and bright fringes observed on the screen.

Fig. 16.2

The pattern shown in Fig. 16.2 is **drawn to scale**.

i. Use Fig. 16.2 to determine accurately the wavelength of the blue light from the laser.

wavelength = ... m **[3]**

ii. The blue light is now replaced by a similar beam of red light.
State and explain the effect, if any, on the fringes observed on the screen.

----

[2]

17. Two transverse waves **P** and **Q** can pass through a point **X**. **Fig. 25.1** shows the displacement-time graphs of a particle at point **X** for each wave independently.

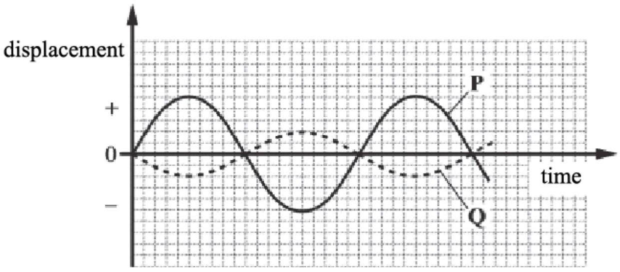


Fig. 25.1

State, with a reason, the motion of the particle at point **X** when both waves are present.

---

[2]

18. This question is about a laser pen.

Define the terms *phase difference* and *coherence*.

phase difference

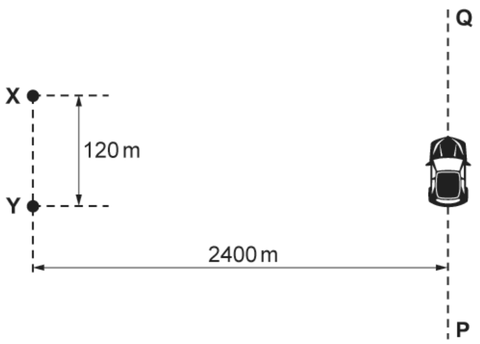
---

coherence

---

[2]

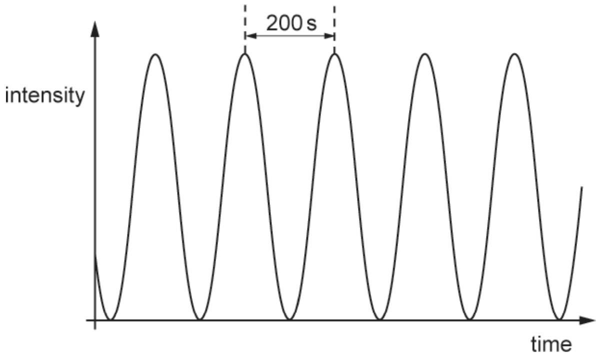
19. The diagram below shows two coherent sources of radio waves **X** and **Y**.



The diagram is **not** drawn to scale.

The radio waves are in phase at **X** and **Y**.
A car moves at a constant speed along the line **PQ**. The line **PQ** is parallel to line **XY**.
The separation between **X** and **Y** is 120 m.
The perpendicular distance between lines **PQ** and **XY** is 2400 m.

The intensity against time graph below shows the variation of the intensity of the radio waves at the position of the moving car.



Explain the maxima and minima in the variation of the intensity.

---

[2]

20. A guitar manufacturer wants to investigate the quality of sound produced from a new uniform polymer string. **Fig. 18.1** shows the string which is kept in tension between a clamp and a pulley. The frequency of the mechanical oscillator close to one end is varied so that a stationary wave is set up on the string.

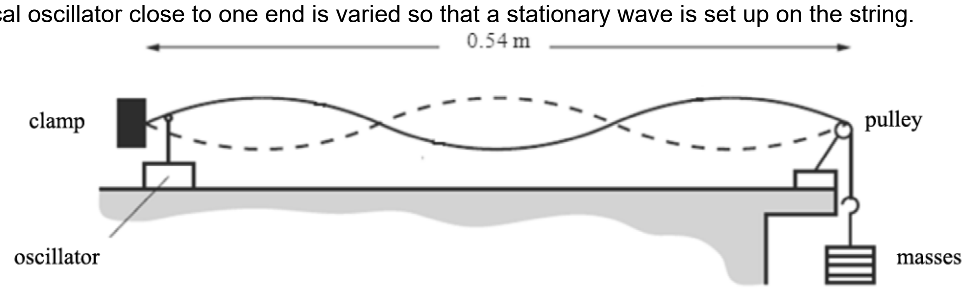


Fig. 18.1

Explain how the stationary wave is formed on this stretched string.

---

[2]

21. Two transmitters, **A** and **B**, emit coherent microwaves in all directions. A receiver is moved at constant speed along the line from **P** to **Q** which is parallel to the line joining the two transmitters, as shown in Fig. 19.2.

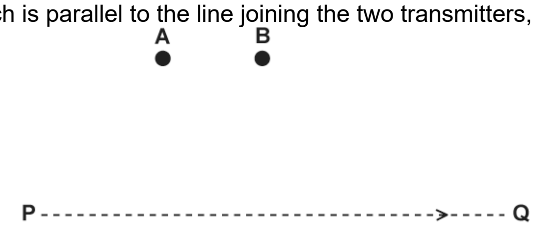


Fig. 19.2

Explain why the output signal from the receiver fluctuates between minimum and maximum values as the receiver moves from **P** to **Q**.

[3]

22 (a). In an experiment to measure the wavelength of yellow light from a sodium lamp, a beam of light from a lamp passes through a pair of narrow slits **S_1** and **S_2**.This produces a pattern of regularly spaced bright and dark lines, called fringes, on a screen as shown in **Fig. 5.1**.

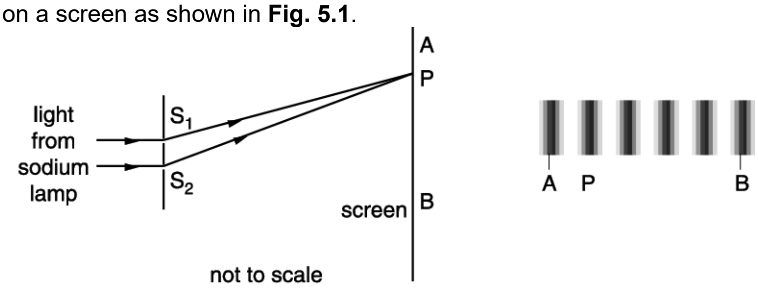


Fig 5.1

A student makes the following measurements:

distance **S_1S_2** = 0.8 mm
distance **AB** on screen = 6.0 mm
distance from slits to screen = 1.6 m

Calculate the wavelength, in nanometre, of the sodium light.

wavelength = ... nm **[3]**

(b). *Fig. 5.2 shows a microscope slide, blackened with graphite paint, with the two slits **S_1** and **S_2** scratched through the paint, very close together, to form the double slit.

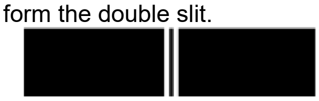


Fig. 5.2

Describe how you could reduce the uncertainty in calculating the value of the wavelength of the light used when carrying out the experiment in **Fig. 5.1**.

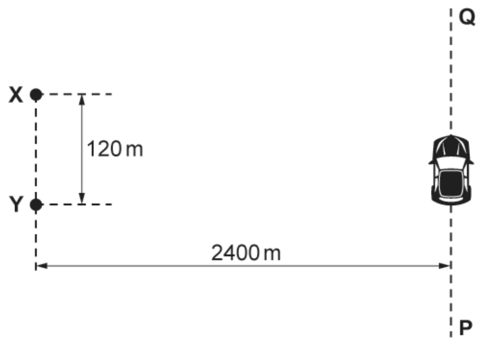
In your answer, include how to achieve the conditions necessary to produce a visible interference pattern on the screen and how you would make the measurements to calculate the wavelength, identifying the measurement which will give the greatest uncertainty.

[6]

(c). To reduce the uncertainty in the calculated value of the wavelength, one student suggests making a different slide with a greater slit separation.
Discuss whether you think this change will reduce the uncertainty.

--- **[3]**

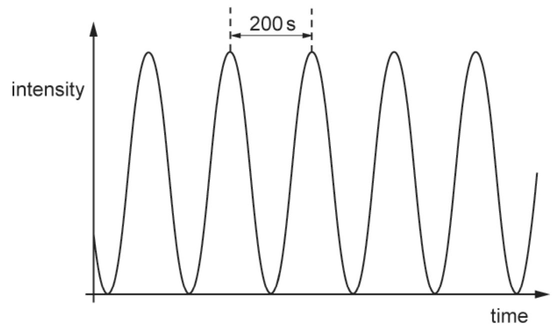
23. The diagram below shows two coherent sources of radio waves **X** and **Y**.



The diagram is **not** drawn to scale.

The radio waves are in phase at **X** and **Y**.
A car moves at a constant speed along the line **PQ**. The line **PQ** is parallel to line **XY**.
The separation between **X** and **Y** is 120 m.
The perpendicular distance between lines **PQ** and **XY** is 2400 m.

The intensity against time graph below shows the variation of the intensity of the radio waves at the position of the moving car.



The time between adjacent maxima is 200 s.
The speed of the car is 18 m s^{-1}.

Calculate the wavelength λ of the radio waves.

λ = ... m **[3]**

24. Fig. 25.2 shows an arrangement used to demonstrate the interference of transverse waves on the surface of water.

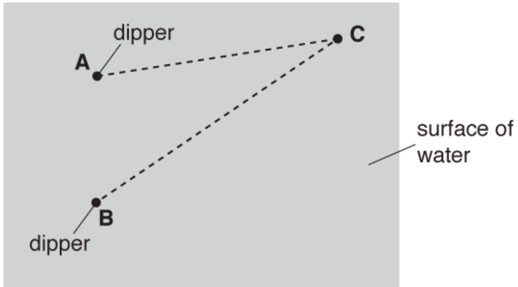


Fig. 25.2 (not to scale)

The dippers **A** and **B** oscillate in phase. Each dipper creates waves of wavelength 3.0 cm. **C** is a point on the surface of the water. The distance **AC** is 10.5 cm and the distance **BC** is 15.0 cm.

i. Explain what is meant by *interference*.

---

[1]

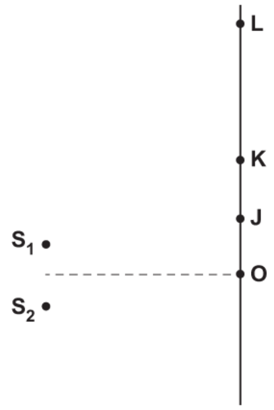
ii. State and explain the type of interference occurring at **C**.

---

[2]

25. Two loudspeakers S_1 and S_2 are connected to a signal generator. The loudspeakers emit coherent sound waves.

A microphone is connected to an oscilloscope. The points **O**, **J**, **K** and **L** all lie on a straight line as shown. The microphone is moved from **O** to **L**.



Not to scale

A series of maxima and minima is observed between **O** and **L**.

The microphone records a maximum at **O**. As it moves towards **L**, the first minimum is observed at **J** and the next maximum at **K**.

The distance between S_1 and **J** is 2.00m and the distance between S_2 and **J** is 2.08 m.

The distance between S_1 and **K** is 2.05m and the distance between S_2 and **K** is 2.21 m.

i. Calculate the path difference at point **J** between the waves from S_1 and S_2 .

path difference = ... m **[1]**

ii. State the phase difference in radian at point **J** between the waves from S_1 and S_2 .

phase difference = ... rad **[1]**

iii. Show that the wavelength of the sound waves is 0.16 m.

[1]

26. At an open air concert two loudspeakers are placed 5.0 m apart at the front of a stage and are sounding a note of frequency 1200 Hz. A row of seats is 30 m from the stage and parallel to it.

Describe and explain, as precisely as possible, what different people along this row will hear. You must include calculations in your answer. The speed of sound in air is 330 m s^{-1}.

[4]

27. A laser **A** is placed close to two slits as shown in **Fig. 25.2**.

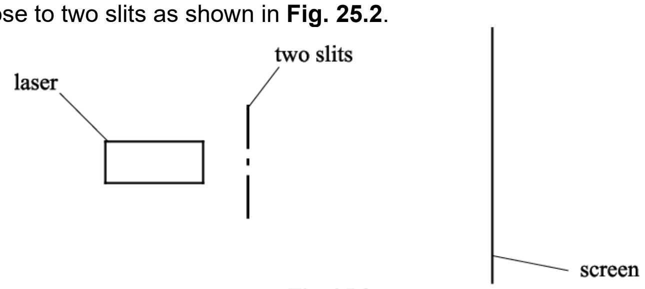


Fig. 25.2

The laser emits monochromatic light. Bright and dark fringes are observed on a screen.

i. Explain why bright and dark fringes are observed on the screen.

[3]

ii. The laser **A** is replaced with another laser **B**. Laser **B** emits light of a different colour with a much greater intensity.

The fringe patterns observed on the screen with these two lasers are shown in **Fig. 25.3**.

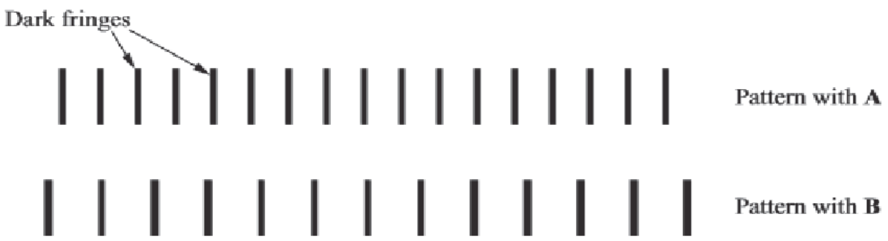


Fig. 25.3 (drawn to scale)

According to a student, laser **B** produces a more spread out fringe pattern because the intensity of its light is much greater than that of laser **A**.

This suggestion is incorrect. Give the correct explanation.

---

[1]

iii. State the effect on the pattern of light seen on the screen when one of the slits is blocked.

---

[1]

28. Fig. 25.1 shows two loudspeakers **L_1** and **L_2** connected to the same signal generator. The loudspeakers emit sound of the same wavelength but with different amplitudes. The points **P** and **Q** are at different distances from the loudspeakers.

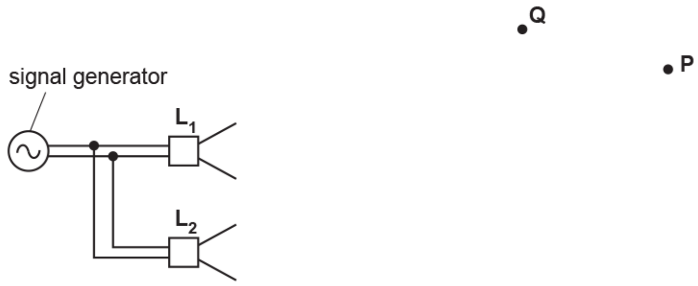


Fig. 25.1

The sound at point **P** from **L_1** alone has displacement x_1. The sound from **L_2** alone has displacement x_2. Fig. 25.2 shows the variation of x_1 with time t.

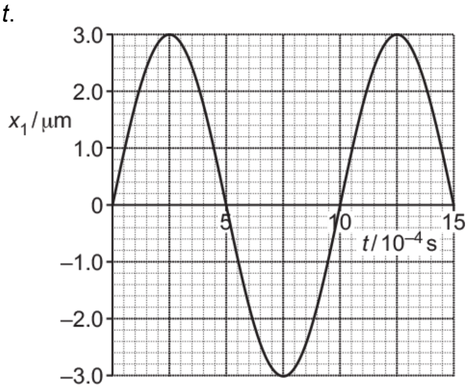


Fig. 25.2

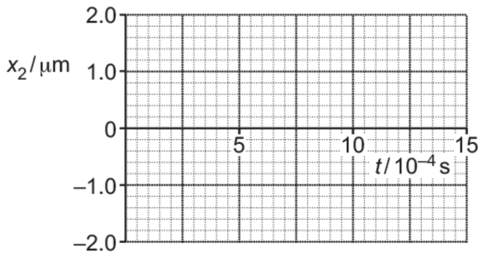


Fig. 25.3

The sound from **L_2** alone at point **P** has amplitude 1.0 µm, a phase difference of 180° compared with the sound from **L_1** and the same frequency as the sound from **L_1**.

i. On Fig. 25.3, draw the variation of x_2 with time t at point **P**.

[1]

ii. Explain why the intensity at **P** due to the sound from both **L_1** and **L_2** is not the same as the intensity of the sound at **P** from only **L_1**.

---

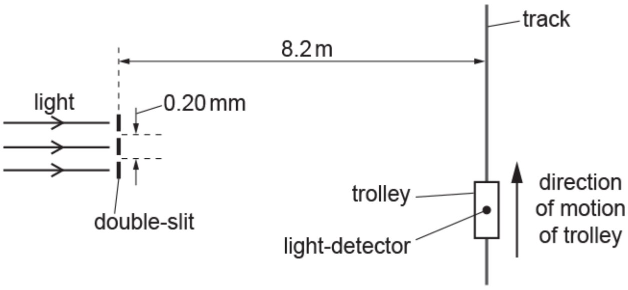
[2]

iii. The wavelength of the sound is 34 cm. The distance **L_1Q** is 200 cm and the distance **L_2Q** is 217 cm. Explain the type of interference occurring at point **Q**.

----

[2]

29. The diagram below shows monochromatic light from a laser incident normally at a double-slit.



The diagram is **not** drawn to scale.

A small light-detector is mounted onto a trolley on a frictionless track. The trolley travels along the track at a constant speed.

The separation between the slits is 0.20 mm. The perpendicular distance between the slits and the track is 8.2 m.

A series of bright and dark fringes are detected at the moving light-detector.

i. Explain, in terms of phase difference, the origin of the fringes.

----

[2]

ii. The speed of the trolley is 0.18 m s^{-1} and the frequency of the light is 4.75×10^{14} Hz.

Calculate the time interval *t* between successive bright fringes.
Write your answer to 2 significant figures.

t = ... s **[3]**

30. * A student carries out two investigations with these electromagnetic waves.

In **investigation 1**, the student rotates the receiver aerial about the horizontal axis joining the two aerials, as shown in **Fig. 5.1**.

In **investigation 2**, the student places a metal sheet behind the receiver aerial. The student moves the sheet backwards and forwards along the horizontal axis joining the two aerials, as shown in **Fig. 5.2**.

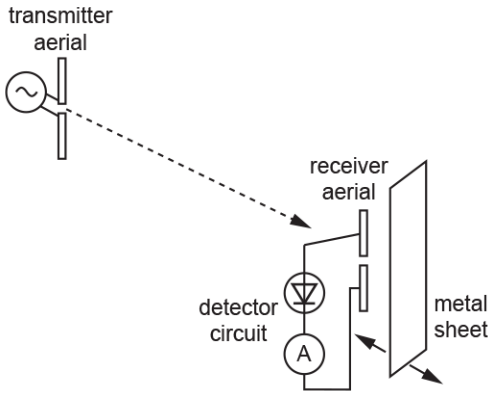


Fig. 5.2

For each of these two investigations:

- Explain why the ammeter sometimes gives a maximum reading and sometimes a zero (or near zero) reading.
- State the orientations of the receiver aerial in **investigation 1**, and the positions of the metal sheet in **investigation 2**, where these maximum and zero readings would occur.

[6]

31. A scientist is investigating the interference of light using very thin transparent material.
A sample of the transparent material is placed in a vacuum.
Fig. 16.2 shows the path of two identical rays of light **L** and **M** from a laser.

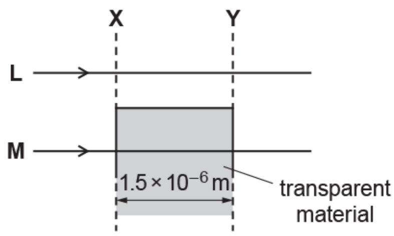


Fig. 16.2

The refractive index of the material is 1.20. The thickness of the material is 1.5 × 10^{-6} m.
The wavelength of the light in vacuum is 6.0 × 10^{-7} m.

i. Show that the difference in time t for the two rays to travel between the dashed lines **X** and **Y** is 1.0 × 10^{-15} s.

t = ... s **[3]**

ii. Calculate the period *T* of the light wave.

t = ... s **[2]**

iii. The rays of light are in phase at the dashed line **X**.

Use your two answers above to state the phase difference φ in degrees between the light rays at **Y**.

φ = ... ° **[1]**

32.  In an experiment to investigate microwaves, a microwave detector **D** is placed between a microwave transmitter **T** and a flat metal sheet.

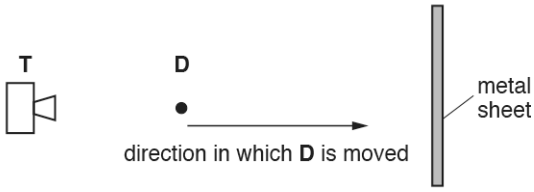


Fig. 7.1

The detected signal at **D** shows regions of maximum and minimum intensity as **D** is moved towards the metal sheet as shown in Fig. 7.1. The distance between **adjacent** regions of maximum and minimum intensities is 72mm.

Explain the presence of the regions of maximum **and** minimum intensity and determine the frequency of the microwaves.

The speed of microwaves in air is 3.0×10^{8} m s^{-1}. **[6]**

33. Fig. 5 shows the variation with distance of the displacement for two progressive waves **P** and **Q**.

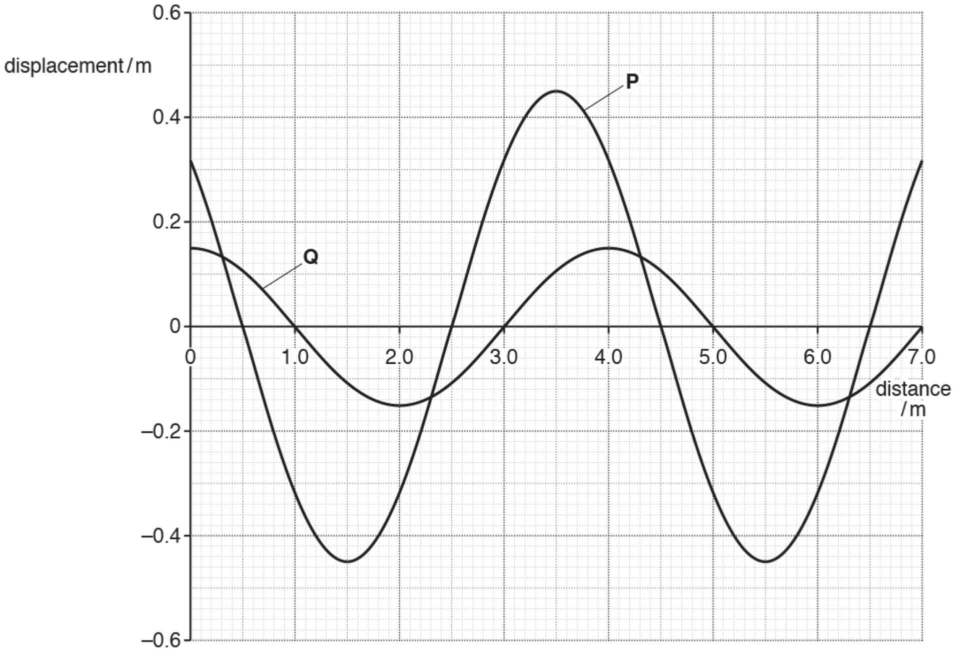


Fig. 5

i. State the amplitude of wave **P**.

amplitude = ... m **[1]**

i. State the wavelength of wave **P**.

wavelength = ... m **[1]**

iii. Determine the phase difference, in radians, between wave **P** and wave **Q**.

phase difference = ... rad **[2]**

iv. Determine the ratio $\frac{\text{intensity of wave } \mathbf{P}}{\text{intensity of wave } \mathbf{Q}}$.

ratio = ... **[2]**

34. This question is about the brightest wavelength (590 nm) of light from a sodium lamp.

*A student is to measure this wavelength by the double-slit method. The lamp, a single slit, a double slit and a clear glass screen are to be set up perpendicular to a common centre line as shown in Fig. 4.

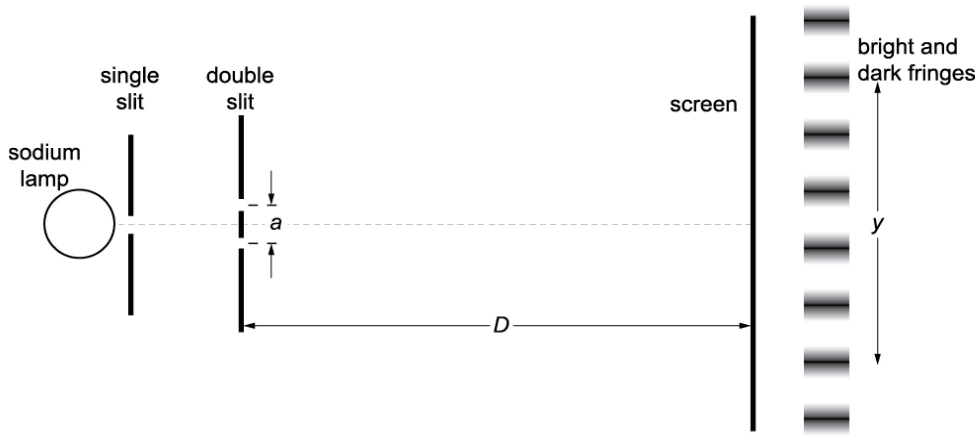


Fig. 4 (not to scale)

A pattern of bright and dark fringes should then be observable through the screen. The screen has millimetre rulings along it. The slit separation *a* is about 0.5 mm and can be measured using a travelling microscope, having a vernier scale to 0.05 mm. The student is also given two 1 metre rulers and a magnifying glass.

The measurements required to calculate the wavelength in the experiment are *a*, *D* and *y* on Fig. 4.

- Explain how the student measures *D* and *y* using the apparatus provided.
- State the uncertainty expected in each measurement and how each could be minimised.
- Estimate the uncertainty in the measured value of the wavelength.

---

[6]

35. *A student wishes to investigate how the fringe spacing x of an interference pattern produced by sound waves varies with the frequency *f* of the sound waves.

It is suggested that $\frac{v}{f} = \frac{ax}{D}$ where

a is the separation of the sources of sound
D is the distance from the sources of sound to the interference maxima and minima
v is the speed of sound in air.

Describe with the aid of a suitable diagram how an experiment can be safely conducted in the laboratory, and how the data can be analysed to determine *v*.

[6]

36. A loudspeaker mounted on a bench is emitting sound of frequency 1.7 kHz to a microphone. Fig. 5.1 shows an illustration of the bulk movement of the air at one instant of time.

Fig. 5.1

Students are given the equipment in Fig. 5.1 together with a metre rule. They are also given a second loudspeaker connected to the same signal generator at 1.7 kHz. They are asked to design an experiment where they would need to take just **one** measurement and be able to determine the value of the speed of sound.

They set up the experiment in two different ways as shown in Fig. 5.3(a) and (b).

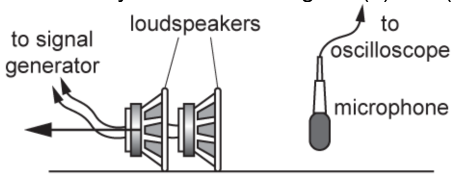


Fig. 5.3(a)

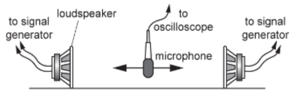


Fig. 5.3(b)

In method **(a)** the microphone is fixed and one loudspeaker is moved to the left as shown in Fig. 5.3(a).
In method **(b)** the microphone is moved to the left or to the right with the loudspeakers fixed a certain distance apart as shown in Fig. 5.3(b).

Describe and explain how both methods can be used to accurately determine the speed of sound. In your description, discuss how the uncertainty in the value for the speed of sound can be minimised in one of the methods, without using any other apparatus.

[6]

37(a). This question is about a laser pen.

Green light from the laser pen passes through a pair of narrow slits **S_1** and **S_2** as shown in Fig. 5.1.

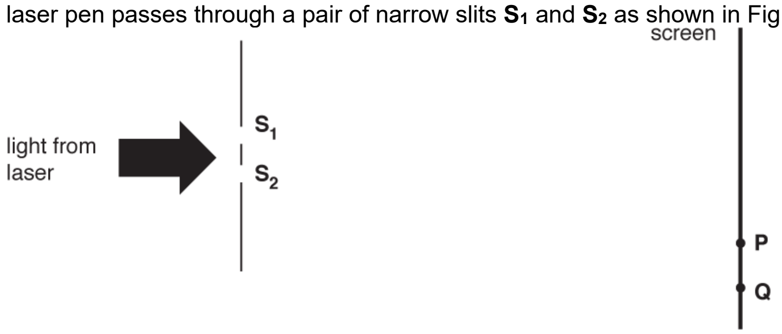


Fig. 5.1

A pattern is produced on a screen consisting of regularly spaced bright and dark lines as shown in Fig. 5.2.

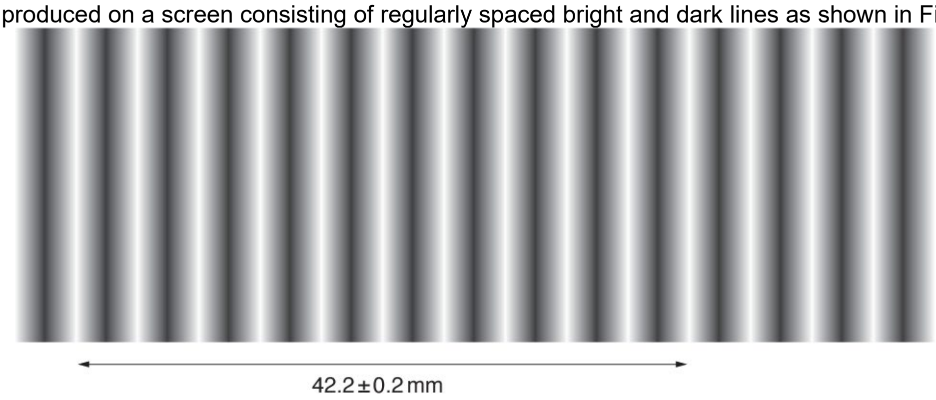


Fig. 5.2

i. Fig. 5.1 shows two points, **P** and **Q**, on the screen. Explain in terms of path difference why point **P** is a bright line and point **Q** is a dark line.

---

[2]

ii. The screen is at a distance of 4.50 ± 0.02 m from the slits and the slit separation is 0.56 ± 0.02 mm.

1. Use Fig. 5.2 to determine the wavelength λ of the light.

λ = ... m **[3]**

2. Determine the percentage uncertainty in λ.

percentage uncertainty = ... % **[2]**

(b). The power of the green light from the laser pen is 50.0 mW. It is now used in a demonstration of the photoelectric effect.

i. Calculate the number of photons n that the laser emits per second.

ii.

n = ... **[2]**

iii. The green light falls on a negatively charged metal plate with a work function of 2.6 eV. Explain whether photoelectrons will be emitted.

---

[2]

38. Some students are asked to use the laboratory 28 mm microwave transmitter **T** and receiver **R** apparatus to design a demonstration to illustrate the principle of a radar speed measuring device.

In **Fig. 3.1**, a movable hardboard sheet **H**, which is a partial reflector of microwaves, is placed in front of the metal sheet **M**, which is fixed.

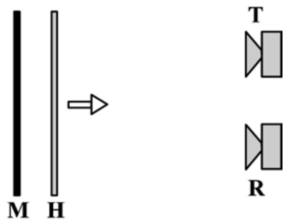


Fig. 3.1

The students expect the detected signal to change between maximum and minimum intensity when sheet **H** moves a distance of 7 mm towards the receiver.

When the detected signal is passed through an audio amplifier to a loudspeaker a sound should be heard. They claim that when the sheet moves at 2.8 m s^{-1} the frequency heard should be 200 Hz. You are to evaluate whether their experiment is feasible and whether their conclusions are correct.

i. Explain why the detected signal strength should vary and discuss what factors will determine whether the difference between maxima and minima can be detected.

[6]

ii. Justify the students' predictions of 7 mm between maxima and minima and a sound at 200 Hz for a speed of 2.8 m s^{-1}.

[3]

39. Fig. 18 shows a loudspeaker placed in front of two narrow slits in a metal plate.

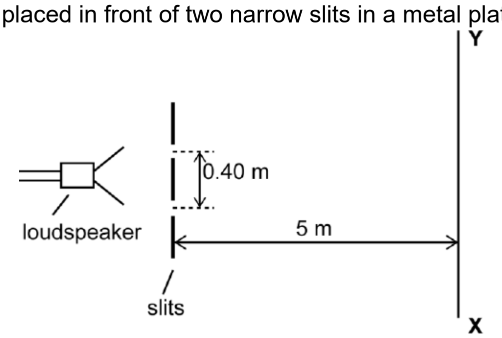


Fig. 18

The loudspeaker emits sound waves of frequency 2.8 kHz. The separation between the centres of the narrow slits is 0.40 m.

A microphone, moved along the line **XY** at a distance of 5.0 m from the slits, detects regions of low and high intensity sound.

The separation between adjacent regions of low and high intensity sound is 0.75 m.

i. Explain how you can use an oscilloscope set to a time-base of 0.1 ms div^{-1} to check that the frequency of sound is 2.8 kHz.

[3]

ii. Explain how the arrangement shown in Fig. 18 produces an interference pattern along the line **XY**.

[4]

iii. Calculate the wavelength of sound.

wavelength = ... m **[3]**

iv. Calculate the speed of sound.

speed = ... m s^{-1} **[1]**

v. State and explain the effect, if any, on the position and the intensity of the maxima when the amplitude of the transmitted waves is halved.

[3]

END OF QUESTION PAPER